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An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario

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ABSTRACT

The energy crisis and environmental degradation are currently two vital issues for global sustainable development. Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which generate thousands tons of municipal solid waste daily, which is one of the important contributors for environmental degradation at national level. Improper management of municipal solid waste (MSW) causes hazards to inhabitants. The management of MSW requires proper infrastructure, maintenance and upgrade for all activities.

The MSWM (municipal solid waste management) system comprises with generation, storage, collection, transfer and transport, processing and disposal of solid wastes.

In the present study, an attempt has been made to provide a comprehensive review of MSW management to evaluate the current status of waste to energy facilities for sustainable management, which will be helpful in tackling this huge quantity of waste and the problem of energy crisis.

A critical review of known MSW management practices/processes in Indian scenario, which will give an idea to investors about the market potential, the maturity of the practicing technologies, and the environmental and economical aspects was also evaluated with its advantages and disadvantages.
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Contents

1. Introduction

Rapid urbanization, industrialization and population growth have led to severe waste management problems in several cities of developing or under developed world like India, Malaysia, Nepal,

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Bangladesh. Although municipal solid wastes (MSWs), a vital part of any society, does not have the catastrophic potential of either global warming or stratospheric ozone depletion, has long posed threats to environmental quality and human health.

According to Union Health Ministry [1], India is an agriculturally based country having present population of about 1020 million. Due to uninterrupted relocation of peoples from rural and semi-urban areas to towns and cities from long time, in India the share of urban population has increased from 10.84% in 1901 to 26.15% in 1991 [2]. As a result, the 677 Class I cities and Class II towns existing in 1991 have increased to more than 700 by 2001 [3]. The increase in population of Class I cities is very high as compared to that of Class II. The urban population accounts for almost one-fourth of the total population and is increasing at a faster rate than the rural population in India. According to Bhinde [4] the population in the urban areas is likely to double by 2010, while the quantity of Municipal Solid Wastes (MSWs) generated is expected to triple. The number of Class I cities with population exceeding 1,00,000 has increased from 212 to 300 during 1981–1991 [2].

The uncontrolled urbanization has left many Indian cities devoid of many infrastructural services such as water supply, sewerage and municipal solid waste management. Most of urban centers worldwide are overwhelmed by severe problems related to solid waste due to lack of seriousness efforts by town/city authorities, garbage and its management. Tremendous increase in the amount of municipal solid waste has been reported in the cities due to an improved lifestyle and social status [5]. Accelerating urbanization accompanied with increasing per capita incomes have also led to rapid increases in MSW generation that have dramatically expanded the burden on local governments in many developing countries for collection, processing, and disposal of MSW in efficient ways [6]. Municipal corporations in developing countries are unable to handle increasing quantities of waste, which results in uncollected waste on roads and in other public places. The most traditional and popular MSW disposal practice worldwide is landfilling or open dumping. Due to limited land availability in some countries and various environmental problems associated, such as gas emissions and leachate production, the technology of landfilling needs to be improved [7].

There is an urgent need to work towards a sustainable solid waste management system, which is environmentally, economically and socially sustainable. Waste to energy generation option can be an alternative for sustainable management of this waste and will be helpful in tackling this huge quantity of waste.

2. Waste generation in India as well as world

Generally, the greater the economic prosperity and higher the proportion of urban population, the greater is the amount of solid waste produced [8]. In India, urban solid waste management has remained one of the most neglected areas. The urban population in India generated about 114,576 $t\,d^{-1}$ of municipal solid waste (MSW) in 1996, which is predicted to increase 4 fold and reach about 440,460 $t\,d^{-1}$ by the year 2026 [8]. This tremendous increase in the amount of MSW generated is due to changing lifestyles, food habits and living standards of the urban population. The MSW collection efficiency ranges between 70 and 90% in the major metro cities in India, whereas in several smaller cities it is below 50% [2]. It has been reported that Indian cities dispose of their waste in open dumps located in the outskirts of the city without any concern for environmental degradation or impact on human health [9]. The economical and infrastructural constraints, including unavailability of land for safe waste disposal, and lack of awareness and fear at all levels restrain progress resulting in inefficient, unsafe urban solid waste management [10]. About 13.9 million residents living in 2.96 million households generates approximately 7000 $t\,d^{-1}$ of MSW at the rate of 0.500 $kg^{-1}\,capita^{-1}\,d^{-1}$ in Delhi [11]. In year 1998, the population of Kuala Lumpur (KL), Malaysia was about 1,446,803, which ascended up to 2,150,000 in year 2005, however, solid waste generation was 2257 $t\,d^{-1}$ in 1998 which is estimated to reach up to 3478 $t\,d^{-1}$ in 2005 [12].

3. Generation of MSW in Indian cities

As per census 2001there are about 593 districts and about 5000 towns in India. Nearly 27.8% of total Indian population i.e. of more than 1 billion lives in urban areas. The projected urban population percentage will be 33.4% of the total by the year 2026. In India management of MSW continues to remain one of the most neglected areas of urban development. In many cities more than half of the solid waste generated remains unattended [13]. This gives rise to unhygienic conditions especially in densely populated areas, which in turn may have serious health and environmental consequences. The quantity of municipal solid waste generated in Indian towns and cities is increasing gradually on account of its increasing population and increased GDP [14]. In the Indian cities amount of solid waste generated annually has been increased from 6 to 48 million tons from year 1947 to 1997 with an annual growth rate of 4.25%, and is anticipated to increase and reach upto 300 million tons by 2047 [15,16]. Physical characteristics of MSW generated in Indian cities are shown in Table 1.

Municipal Solid Waste (Management and Handling) Rules, 2000 endorses the accountability of the municipal authorities to build up appropriate solid waste management system and provide suitable sites for controlled disposal and sustainable treatment of waste in a city. But, in most of the Indian cities, municipal authorities lack suitable strategies, infrastructure and financial resources for organized and sustainable solid waste management [17]. Therefore, more than 90% of solid waste is directly disposed off on land in an unsystematic manner, mainly in open dumps and poorly managed landfills in the low-lying areas outside the cities, posing the significant hazards to nearby environment [18].

Geographical factors, the level of economic development and urban population density influences the generation of MSW in a country. Existence of industries within the municipal jurisdiction and level of industrialization all together significantly influences the quantity as well as quality of waste, as most of the industrial wastes from small and medium scale industries direct their waste through the municipal system. Another source of waste that finds their way to MSW is the waste from hospitals and clinics. As in most of the countries most of the smaller units does not have any specific means of managing these wastes. When mixed with MSW these wastes not only pose threat for environmental health hazard, but may have long term effect on environment [19].

Asia-Pacific region generates about 700 million tons of total solid waste yearly; however industrial activities generate about 1900 million tons of waste per year [20]. The industrial wastes are markedly different and specific to each serving industry. In this region 2.6 billion tons of total amounts of waste is generated every year. It is also estimated that about 30–50% of the generated waste remains unattended [20]. According to TERI [21] about 80% of the municipal solid waste generated in National Capital Territory (NCT) of Delhi is being collected, and the rest remains unattended on streets or in small dumps. About 90% of the MSW collected is disposed in landfills, and the remaining is composted [22,23].

European Union generates about 1.3 billion tons of wastes annually with agriculture contributing another 700 million tons [24]. Due to the tremendous increase in population rise and MSW generation the situation over the last two decades has been aggravated. The higher levels of resource consumption have resulted in

Table 1
Physical characteristics of MSW in Indian cities (population wise) [87].

Population range (million)	No of cities surveyed	Compostable matter	Metal	Inert material	Paper	Rubber, leather and synthetics	Glass
0.1–0.5	12	44.57	0.33	43.59	2.91	0.78	0.56
0.5–1.0	15	40.04	0.32	48.38	2.95	0.73	0.56
1.0–2.0	9	38.95	0.49	44.73	4.71	0.71	0.46
2.0–5.0	3	56.57	0.59	40.07	3.18	0.48	0.48
5.0 and above	4	30.84	0.8	53.9	6.43	0.28	0.94

All values are in percentage and are calculated on wet weight basis.

severe impacts, leading to constraints and environmental degradation. According to Jin et al. [25] MSW characteristics significantly depends on lifestyles, cultural traditions, economic status, literacy rates, food habits, climatic and geographical conditions of the area. Municipal solid waste from Europe includes the waste originating from households, public buildings areas, as well as in small commerce [26]. It does not include human faeces (night soil) and the sewage sludge generated in wastewater treatment plants. Demolition debris, agricultural throw away, industrial wastes as well as hospital fritter away are also not incorporated. In contrast, MSW from Asia includes the waste generated by human settlements as well as from the industries producing consumer goods including the waste from demolition debris and agricultural. Therefore waste from the Asian cities can have a significant hazardous potential than that of the European.

4. Types of waste management practices

Municipal solid waste contains recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) [27–29]. It is proved from the above discussions that a wide variety of substrates/raw materials are available for exploitation and conversion to the bio-energy. A variety of processes exist for waste conversions. The most used of these are thermal conversions (incineration, fast and slow pyrolysis, gasification, production of refuse derived fuel (RDF)), bio-chemical (composting, vermicomposting, anaerobic digestion/biomethanation) and chemical conversions (trans-esterification and other processes to convert plant and vegetable oils to biodiesel). Choice of conversion process depends on the type, property and quantity of biomass feedstock, the desired form of the energy, end use requirements, environmental standards, economic conditions and project-specific factors.

This section presents a critical review of these known MSW management practices/processes in Indian scenario, which will give an idea for investors about the market potential, the maturity of the practicing technologies, and the environmental and economical aspects. Not all technologies are equally good. Each one of them has its own advantages and limitations.

4.1. Thermal conversions

Thermal conversion is the component of a number of the integrated waste management solutions proposed in the various strategies [30]. Combustion, gasification and pyrolysis are the thermal conversion processes available for the thermal treatment of solid wastes. As shown in Fig. 1, different by-products are produced from the application of these processes and different energy and matter recovery systems can be used to treat these products [31].

4.1.1. Incineration

Waste management and utilization strategies are major concern in many countries. Incineration is a common technique for treating waste, as it can reduce waste mass by 70% and volume by up to 90%, as well as providing recovery of energy from waste to generate electricity.

The incineration process is separated into three main parts: incineration, energy recovery and air pollution control [32,33]. Emissions from the incineration of MSW along with other municipal wastes contain air pollutants (SO*x*, NO*x*, CO*x*). Thus the incineration of MSW may result in air pollution, unless the incinerators are well equipped with appropriate pollutant control accessories. It produces energy in the form of steam or electricity, if it is combined with an appropriate energy recovery system. This comprises of a lined furnace, fire grate, air blowers and range in capacities from 50 kg to 20 t h^{-1}. Incineration process takes places between 750 °C to 1000 °C and can be coupled with steam and electricity generation process. A volume reduction of 80–90% is possible by this method.

Mass incineration without pretreatment of the MSW with electricity generation is regarded as the most reliable and economical option due to the following reasons. (i) The majority of wastes will burn without giving rise to noxious products of combustion (HCI, HF, SO_2 and NO*x*) in significant quantities. (ii) The volume and mass occupied by the waste is greatly reduced. A small volume of incombustible residues are left. The heat of combustion is recovered in a waste heat boiler for steam generation. (iii) Waste in its initial form may be objectionable in nature containing decaying organic matter and whatever. The incineration process produces an effectively sterile ash residue.

4.1.2. Pyrolysis

Of the disposal methods, pyrolysis of wastes, a thermal method of treatment requiring the heating of wastes in an oxygen free atmosphere is of interest. Various advantages claimed of the pyrolysis process are: (a) significant reduction in volume of the waste (<50–90%), (b) production of solid, liquid and gaseous fuels from waste, (c) storable/transportable fuel or chemical feed stock is obtained, (d) least environmental problem, (e) desirable process as energy is obtained from renewable sources like municipal solid waste or sewage sludge, (f) the capital cost is comparatively less than that of incineration process, and (h) once started, the process is self-sustaining. Pyrolysis is an indirect gasification process with inert gases as the gasification agent [34].

Various pyrolysis processes have been briefly described in this section. Conventional pyrolysis (slow pyrolysis), proceeds under a slow heating rate with solid, liquid and gaseous products in significant portions [35]. It is an ancient process used mainly for charcoal production. Vapours can be continuously removed as they are formed [36]. But the fast pyrolysis is associated with tar, at low temperature (850–1250 K), and/or gas, at high temperature (1050–1300 K). At present, the preferred technology is fast or flash pyrolysis at high temperatures with very short residence time [37]. Fast pyrolysis (more accurately defined as thermolysis) is a process in which a material, such as biomass, is rapidly heated to high temperatures in the absence of oxygen [37]. Table 2 shows the range of the main operating parameters for pyrolysis processes [38], whereas Table 3 shows the composition of product gas from

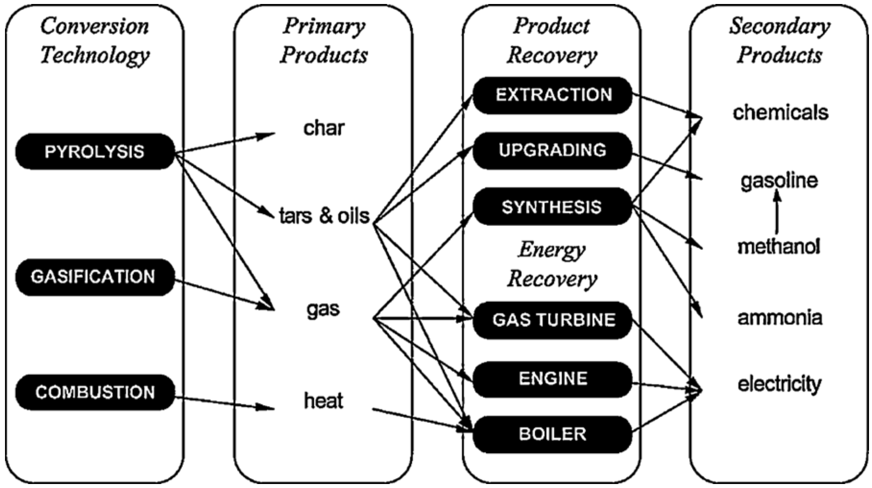

Fig. 1. Thermal conversion process and products [31].

Table 2
Main operating parameters for pyrolysis process [38].

Parameters	Conventional pyrolysis	Fast pyrolysis	Flash pyrolysis
Pyrolysis temperature (K)	550–900	850–1250	1050–1300
Heating rate (K/s)	0.1–1	10–200	>1000
Particle size (mm)	5–50	<1	<0.2
Solid residence time (s)	300–3600	0.5–10	<0.5

Table 3
Composition of pyrolysis gas from municipal solid waste [39].

Constituent	Amount, vol.%
CO	35.5
CO_2	16.4
CH_4	11.0
H_2	37.1
Calorific value, kcal/Nm^3	3430

MSW [39]. Table 4 shows the yields of char, liquid and gas from the various biomass pyrolysis options [40].

4.1.3. Gasification

Gasification is process in which partial combustion of biomass is carried out to produce gas and char at the first stage and subsequent reduction of the product gases, chiefly CO_2 and H_2O, by the charcoal into CO and H_2. Depending on the design and operating conditions of the reactor the process also generates some methane and other higher hydrocarbons (HCs) [41]. Broadly gasification can be defined as the thermochemical conversion of a solid or liquid carbon-based material (feedstock) into a combustible gaseous product (combustible gas) by the supply of a gasification agent (another gaseous compound). The gasification agent allows the feedstock to be quickly converted into gas by means of different heterogeneous reactions [42–44]. The combustible gas contains CO_2, CO, H_2, CH_4, H_2O, trace amounts of higher hydrocarbons, inert gases present in the gasification agent, various contaminants such as small char particles, ash and tars [45].

If the process does not occur with help of an oxidising agent, it is called indirect gasification and needs an external energy source (Figs. 2 and 3) [46,47]. Steam is the most commonly used indirect

Table 4
The typical yields of char, liquid and gas from the various biomass pyrolysis options [40].

Thermal degradation	Residence time (s)	Upper temp (K)	Char	Liquid	Gas
Conventional pyrolysis	1800	470	85–91	7–12	2–5
	1200	500	58–65	17–24	8–12
	900	550	44–49	26–30	16–24
	600	600	36–42	27–31	23–29
	600	650	32–38	12–17	27–34
	600	850	27–33	20–26	36–41
	450	950	25–31	12–17	48–54
Slow pyrolysis	200	600	32–38	28–32	25–29
	180	650	30–35	29–34	27–32
	120	700	29–33	30–35	32–36
	90	750	26–32	27–34	33–37
	60	850	24–30	26–32	35–43
	30	950	22–28	23–29	40–48
Fast pyrolysis	5	650	29–34	46–53	11–15
	5	700	22–27	53–59	12–16
	4	750	17–23	58–64	13–18
	3	800	14–19	65–72	17–24
Gasification	1800	1250	7–11	4–7	82–89

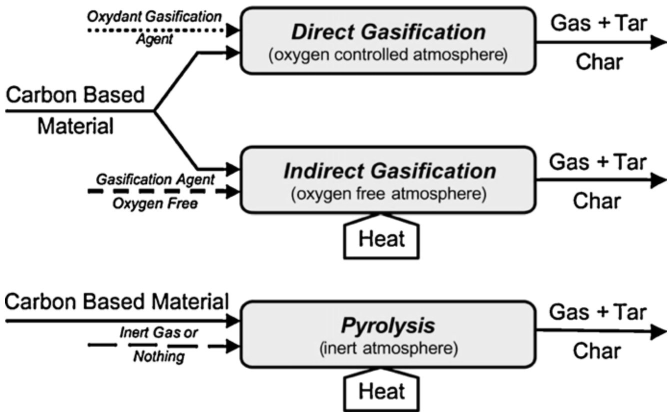

Fig. 2. Gasification and pyrolysis processes [34].

gasification agent, because it is easily produced and increases the hydrogen content of the combustible gas [46].

An issue common between all developed countries is the production of excessive amounts of waste per capita. As societies have developed, the quantity of waste material generated has also increased to a level that is unsustainable. Along with increasing awareness of the general public of the damage caused to the environment, there is a urgent need to plan and implement sustainable and integrated strategies for managing and treating waste materials has become a priority for many local authorities [48].

A gasification system is made up of three fundamental elements: (1) the gasifier, helpful in producing the combustible gas; (2) the gas clean up system, required to remove harmful compounds from the combustible gas; (3) the energy recovery system. The system is completed with suitable sub-systems helpful to control environmental impacts (air pollution, solid wastes production, and wastewater). A sufficiently homogeneous carbon-based material is required for a correct and efficient gasification process. Therefore several types of waste cannot be treated in the gasification process and for certain types an extensive pre-treatment is required (refuse derived fuel). Instead there are several types of waste that are directly suitable for the process; these are: paper mills waste, mixed plastic waste, forest industry waste and agricultural residues [49]. The gasifier is a reactor in which the conversion of a feedstock into fuel gas takes place. There are three fundamental types of gasifier: (1) fixed bed, (2) fluidised bed and (3) indirect gasifier. In Table 3, the main advantages of the different type of gasifiers are summarised.

Gasification process represents a future alternative to the waste incinerator for the thermal treatment of homogeneous carbon-based waste and for pre-treated heterogeneous waste. As shown in Fig. 4, gasification should be considered as an option for the thermal treatment of wastes in an integrated waste management system. For example, co-firing and co-gasification (gasification of solid waste with coal or biomass in the same gasifier) are interesting solutions for both decentralised energy systems and waste management systems in rural communities [34]. According to Belgiorno et al. [34] gasification technology has been applied for the energy production from solid wastes via RDF utilization.

4.2. Biochemical conversion

Biochemical conversion processes make use of the enzymes of bacteria and other micro-organisms to breakdown biomass. In most of the cases micro-organisms are used to perform the conversion process: anaerobic digestion, fermentation and composting. Biochemical conversion is one among the few which provide environment friendly direction for obtaining energy fuel from MSW. Anaerobic digestion is helpful in lessening the amount of organic solid waste and recovering energy. Basically, organic fraction of MSW is a potential feedstock for anaerobic digestion [50–54]. Typically the organic fraction may be digested and the biogas may be utilised either for combined heat and power (CHP) or as a transport fuel however, non-recyclable non-organic fraction from MSW may be either incinerated or gasified. During the decomposition process this organic fraction, the temperature rises and may reach as high as 65 °C but starts to fall after 1–2 months. However the process of fermentation goes on for a long time and a number of gases are produced, including small amounts of CO and H_2S. Under anaerobic

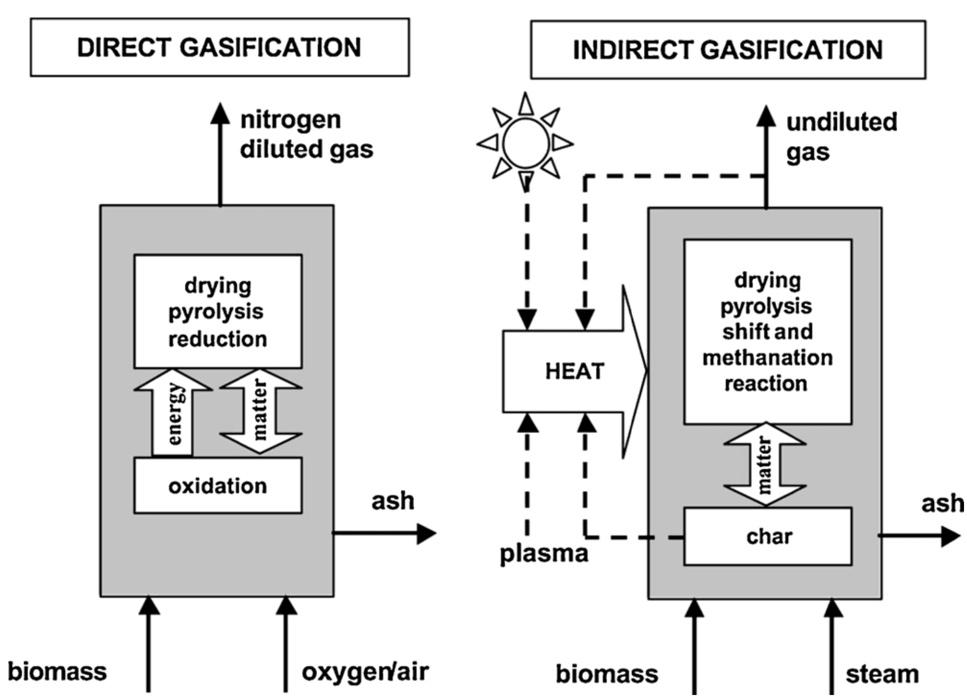

Fig. 3. Direct and indirect gasification processes [34].

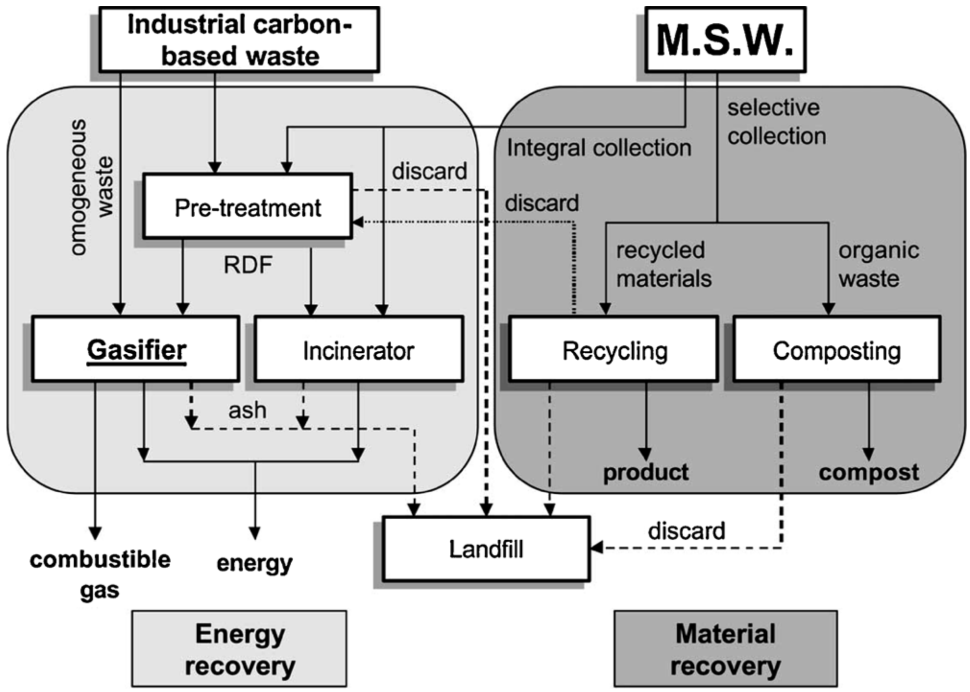

Fig. 4. Integrated waste management system [34].

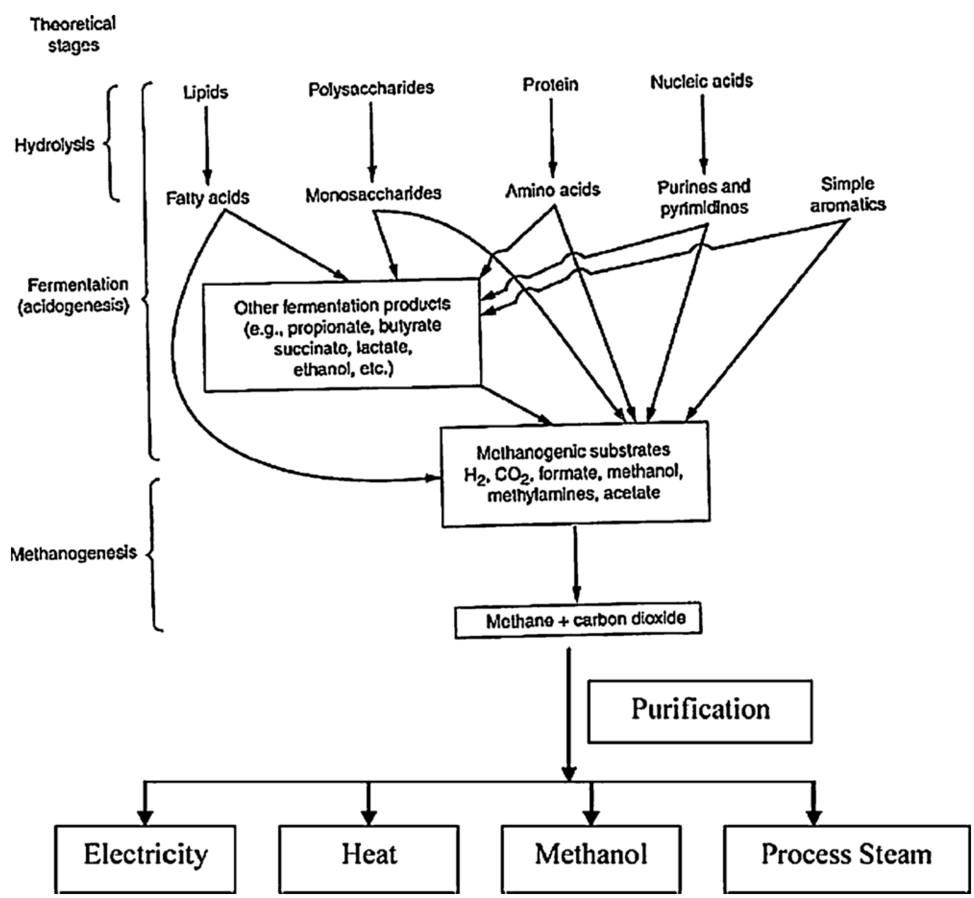

Fig. 5. Flow sheet of anaerobic digestion process [55].

conditions methane is produced. Methane (high-heat gas) can be efficiently converted into methanol. Fig. 5 shows steps involved in typical anaerobic process [55]. It has been estimated that by controlled anaerobic digestion, 1 ton of MSW produces 2–4 times as much methane in 3 weeks in comparison to what 1 ton of waste in landfill will produce in 6–7 years [56,57].

4.3. Landfilling

In many metropolitan cities, open, uncontrolled and poorly managed dumping is commonly practiced, giving rise to serious environmental degradation problem. In India, more than 90% of MSW in cities and towns are directly disposed of on land in an unsatisfactory manner (Das et al. [18]). Such dumping activity in many coastal towns had resulted in heavy metals rapidly leaching into the coastal waters. In larger towns or cities like Delhi, the availability of land for waste disposal is very limited [58–63]. In the majority of urban centers, MSW is disposed of by means of depositing it in low-lying areas outside the city without following the principles of sanitary landfilling. Compaction and levelling of waste and final covering by soil are rarely observed practices at most disposal sites, and these low-lying disposal sites are devoid of a leachate collection system or landfill gas monitoring and collection equipment [64]. As no segregation of MSW at the source takes place, all of the wastes including infectious waste from hospitals normally find its way to the disposal site. Oftently, industrial waste is also deposited at the landfill sites designed for domestic waste [65]. Sanitary landfilling is an acceptable and recommended technique for final disposal of MSW. It is a necessary component of MSWM, since all other options generate some residues that must be disposed of through landfilling. However, it appears that landfilling would continue to be the most widely adopted practice in India in the coming few years, during which certain improvements will have to be made to ensure the sanitary landfilling [66].

5. Current MSW management scenario in India

Municipal solid waste management (MSWM) is a critical problem for developing countries. The waste generated in the developing countries is almost similar in composition, the variation between regions being dictated by the climatic, cultural, industrial, infrastructural and legal factors. Due to rapid urbanization and uncontrolled population growth rate, SWM has become acute in India. Indian cities now generate eight times more MSW than they did in 1947. It is estimated that India's current population of 1200 million will continue to grow at the rate of 3–3.5% per annum. Presently, about 90 million tons of solid waste are generated annually as by products of industrial, mining, municipal, agricultural and other processes. The amount of MSW generated per capita is estimated to increase at a rate of 1–1.33% annually [66]. Due to its simplicity and low capital requirements composting and landfilling processes accounts for approximately 60% of the market. The breakdown of the market in terms of technologies for MSW treatment and disposal is shown in Table 5 [67,68]. The main load that the increase in solid waste generation would impose is evident from the fact that the cumulative requirement of land (base year 1997), for disposal of MSW, would amount to around 1400 km^2 by

Table 5
Market share of different MSW management technologies [69].

Technology	Present market share
Composting	50
Anaerobic digestion	30
Pelletization	10
Sanitary landfill	10

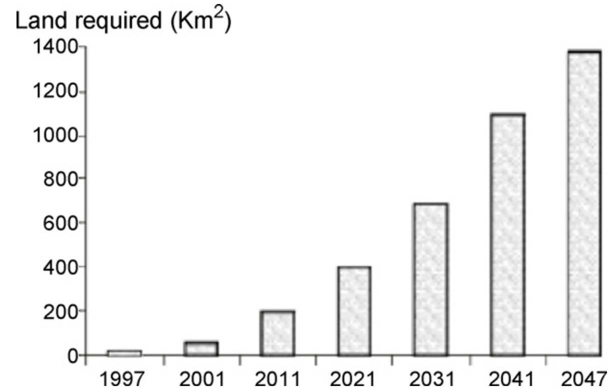

Fig. 6. Cumulative land requirement for disposal of municipal solid waste (km^2) [65].

2047 (Fig. 6) [69]. Currently, the existing dumping grounds in India are full and overflowing beyond capacity. It is difficult to get new dumping yards and if at all available, they are far away from the city and this adds to the exorbitant cost of transportation.

There are atleast seven domestic companies offering technologies and/or turnkey project services for implementing MSW treatment and disposal projects in the country [70]. The Indian government has enhanced the outlay for energy recovery from urban and agricultural waste in the fiscal 1999–2000 budget. This has given a boost to projects promoted through the national program on energy recovery from urban, municipal, and industrial wastes, and projects on development of high-rate bio-methanation processes as a mean of reducing green house gases emission. Financial incentives to state nodal agencies, municipal corporations, financial institutions, project developers, and technology providers for setting up waste to energy (WTE) projects are being provided by the Ministry of Nonconventional Energy Sources (MNES) under these programs [71,72]. In Madhya Pradesh State, the first major industrial waste treatment plant on WTE principle is being commissioned at Som Distilleries, Bhopal, on June 5, 1999. This project, at an estimated cost of U.S. $325 000, uses a biomethanation digester to produce biogas. Approximately 900 cm^3 of raw spent wash effluent is generated per day. This raw wash is expected to generate 34 000 m of biogas per day. The plant capacity is rated at 2.7 MW of power and is expected to generate minimum 16×10 kW h per annum. In Uttar Pradesh State, the Nonconventional Energy Development Agency (NEDA), Department of Additional Sources of Energy, Government of Uttar Pradesh, and the Maharastra Energy Development Agency (MEDA) invited potential promoters to set up power projects based on MSW [73]. The Chennai city, the Tamilnadu state capital, generates approximately 2500 tons of MSW per day. Two international companies, CGEA (Singapore) and Albucheri (Kuwait) are in a race along with two Indian companies namely Swacherita Corporation (Bangalore) and the state-owned Tamilnadu Agro Engineering Federation to get the government approval for the collection and disposal of MSW. A 15-MW waste to energy project has being established by Energy Development Ltd. (Australia) [74]. The State bank of India and Canara Bank is going to finance the project, including a waste treatment plant, estimated cost of which is U.S. $37.5 10. Fig. 7 shows the municipal solid waste management (MSWM) system in India [75].

The chemical characteristics of the municipal solid waste in India are given in Table 5, however, Table 6 shows zone wise solid waste generation in India [76]. The compostable matter in the MSW is ranging form 30.84% in very big cities whose population is above 5 million to 56.57% in cities having population between 2.0 and 5.0 million. On an average the compostable matter percentage is 42.194%, which is a very good amount for anaerobic digestion. The

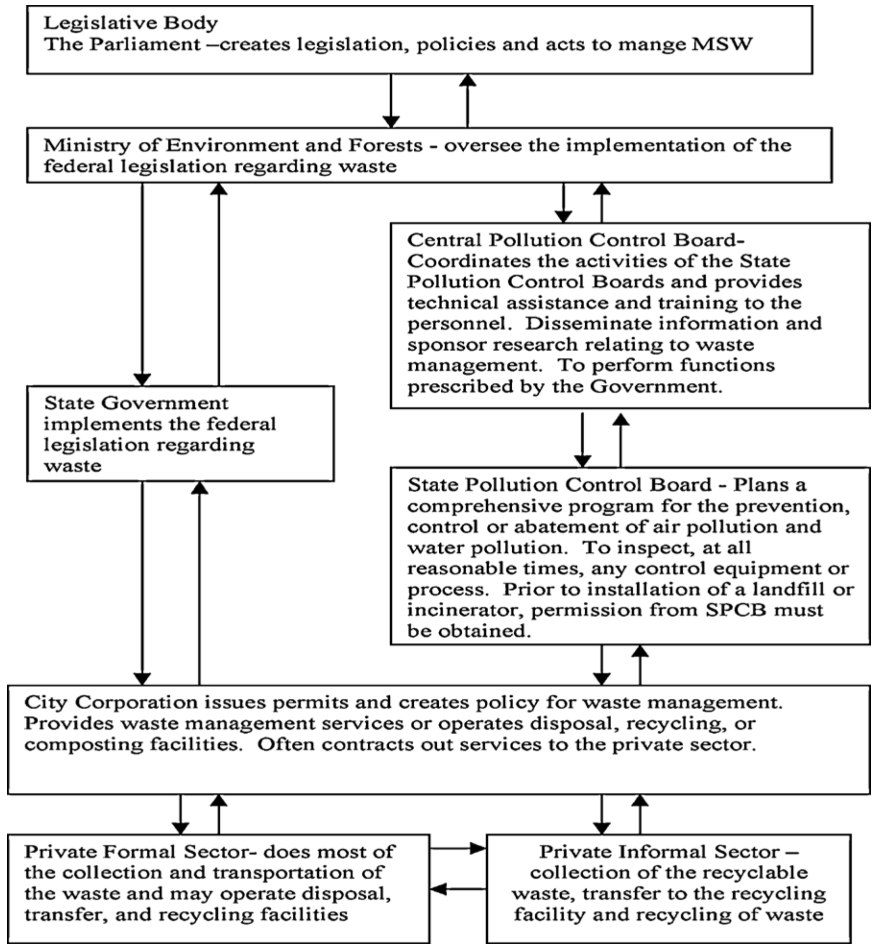

Fig. 7. Municipal solid waste management (MSWM) systems in India [65].

Table 6
Chemical characteristics of MSW in Indian cities population wise [5].

Population range (million)	Nitrogen as total N	Phosphorus as P_2O_5	Potassium as K_2O	C/N ratio	Calorific value (kcal/kg)
0.1–0.5	0.71	0.63	0.83	30.94	1009.89
0.5–1.0	0.66	0.56	0.69	21.13	900.61
1.0–2.0	0.64	0.82	0.72	23.68	980.05
2.0–5.0	0.56	0.69	0.78	22.45	907.18
5.0 and above	0.56	0.52	0.52	30.11	800.70

C/N ratio which is very important in the conversion process is varying from 21.13 to 30.94, whereas the calorific values are varying from 800.70 to 1009.89 kcal/kg. To obtain the data regarding the quantity of MSW in the country, it was divided into 4 zones namely South, North, West and East. Each zone is further divided into four group's namely very big, big, medium and small cities. From the information it is visible that the north zone is producing maximum waste when compared to the other zones. The total waste produced is 97,173 t d^{-1} (Table 7) [77]. Studies had been carried on anaerobic digestion of municipal solid waste [78] and it is found that biogas can be generated at a rate of 95 m^3 t^{-1} of solid waste. The biogas generation potential for the MSW is estimated as 9.23 mm^3 day^{-1}.

6. Energy generation potential from MSW and its applications for WTE technology

A universal factor to all developed countries is the production of excessive amounts of waste per capita. As societies have developed, the amount of waste material generated has increased to a level that is unsustainable. This, taken together with the increasing awareness of the general public of the damage caused to the environment, means that there is a need to plan for and implement sustainable and integrated strategies for handling and treating waste materials has become a priority for many local authorities [79].

Municipal wastes generation in rural areas is not significant and no data is available on quantitative basis. Hence, in this paper, the energy potential of municipal solid waste generated by urban population has been considered by us. In India, based on 1991 census data, the estimated quantity of MSW generated in 10 major cities annually is more than 10 Mt. The disposal of such enormous quantities has become a major problem. Thus, the utilization of MSW for energy would mean a solution of this problem.

The approximate methane emission all over India as per 2001 census was calculated using an IPCC default (1996) method by NSWAI. The total quantity of methane emitted out of MSW generated in India as a whole was approximately 4612.69 MT d^{-1}. An economic feasibility study done by IGIDR (Indira Gandhi Institute of Development Research) for Mumbai city indicates that for a total population of 10 million producing 1.82 MT of MSW per year, the net methane that can be produced is equivalent to about 8.5 GJ

Table 7
Solid waste generation in India [77].

Zone	City classification	Solid waste (tpd)
South	Very big	10,215
	Big	490
	Medium	4325
	Small	9690
		24,720
North	Very big	13,110
	Big	4372
	Medium	4137
	Small	8063
		29,682
Western	Very big	18,479
	Big	2790
	Medium	2958
	Small	4559
		28,785
Eastern	Very big	6962
	Big	934
	Medium	1158
	Small	4931
		13,986
	Total	97,173

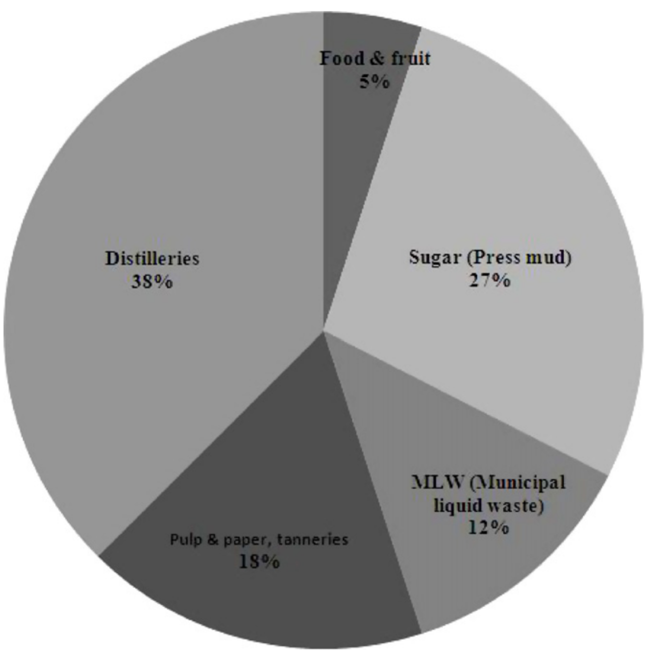

Fig. 8. Energy recovery potential (MWe) of different wastes [86].

(Giga Joules). According to TEDDY (2002–2003) the energy recovery potential from different waste is as shown in Fig. 8.

Energy recovery potential of MSW is 900 MWe out of total 1700 MWe amounting to about 53%. Thus, utilizing MSW dumping grounds for energy production would represent a favorable and useful solution to the existing municipal solid waste disposal problem [80]. Unlike developed countries, in developing countries like India, the landfill system is not very prominent and well managed. Therefore, it is not practicable to collect the methane, which escapes into the environment from waste dumps, either for flare or use as a source of energy. Systems are needed to be developed to collect methane and generate energy. The total MSW generated in 1997 was 23.5 Mt. Based on the MSW collected in 5 large cities, the average MSW landfilled is about 85%. The estimated energy potential of landfill gas in the year 1997 is about 86 PJ (Table 8). It has been assumed that 90% of the MSW generated will be landfilled in 2010. The estimated energy potential of landfill gas (LFG) in the year 2010 is 219 PJ. Development of a landfill system for energy recovery would be a good option in warm climatic conditions of India. A system can be developed for successful collection and transportation of the MSW and efficient energy generation. An economic feasibility study has been done by IGIDR for Mumbai city [81]. For a total population of 10 million producing 1.82 Mt of MSW per year, the net methane that can be produced is equivalent to about 8.5 GJ. In the proposed landfill system, the disposal cost of solid waste varies from 222 to 566 Rs/t. In the conventional waste management system the disposal cost is estimated to be 4054 Rs/t.

Table 9
Municipal solid waste to energy: estimated potential.

Period	Projected MSW generation (TPD)	Potential for power generation (MWe)
2007	148,000	2550
2012	215,000	3650
2017	304,000	5200

Source: 11th Planning Commission.

Along with environmental management concerns, energy in the form of biogas, heat or electricity is seen as a bonus, which improves the viability of such projects [82,83]. The major benefits of recovery of energy from MSW is reduction in the quantity of waste by 60–90%, reduction in the demand for land as well as cost of transportation of wastes to far-away landfill sites and net reduction in environmental pollution, besides generation of substantial quantity of energy. As per 11th planning commission the estimate potential for MSW to energy is given in Table 9. Three demonstration projects, with subsidy from Ministry of New and Renewable Energy (MNRE), Government of India, for energy recovery from MSW with an aggregate capacity of 17.6 MW were been installed at Hyderabad (6.6 MW), Vijayawada (6 MW) and Lucknow (5 MW) in collaboration with local urban bodies with limited success [84,85]. Main parameters determining the potential of energy recovery from wastes (including MSW) are: quantity of waste and physical and chemical characteristics (quality) of the waste. The actual production of energy will depend upon specific treatment process in use, the selection of which is also significantly dependent upon the above two parameters. The important physical parameters requiring consideration include constituent's size, density and moisture content. Smaller size of the constituents helps in faster decomposition of the waste. Wastes of the high density reflect a high fraction of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high

Table 8
Energy potential of MSW from landfill gas [81].

MSW generated ($Mt\,yr^{-1}$)	Quantity land filled @ 0.85% of total MSW ($Mt\,yr^{-1}$)	DOC content in MSW @ fraction 0.17 ($Mt\,yr^{-1}$)	Dissimilated DOC fraction (Mt) @ 0.77	Fraction CH4 ($Mt\,yr^{-1}$)	Energy value $PJ\,yr^{-1}$
23.5 (1997)	20.0	3.40	2.61	1.73	86
56 (2010)	50.4 @ 90%	8.56	6.59	4.38	219

DOC: degradable organic carbon.

Table 10
Desirable range of important waste parameters for technical viability of energy recovery [2].

Waste treatment method	Basic principle	Important waste parameters	Desirable range[a]
Thermo-chemical conversion	Decomposition of organic matter by action of heat	Moisture content	<45%
		Organic/	
		Volatile matter	>40%
		Fixed carbon	<15%
		Total inerts	<35%
		Calorific value (net calorific value)	1200 k-cal kg^{-1}
Bio-chemical conversion	Decomposition of organic matter by microbial action	Moisture content	>50%
		Organic	>40%
Anaerobic digestion/		Volatile matter	
Bio-methanation		C/N ratio	25–30

[a] Indicated value pertain to suitability segregated/processed/mixed wastes and do not necessarily correspond to wastes as received at the treatment facility.

Table 11
Advantages and disadvantages of different technological options [2].

Advantages	Disadvantages
Anaerobic digestion	
Energy recovery with production of high grade soil conditioner.	Heat released is less-resulting in lower and less effective destruction of pathogenic organisms than in aerobic composting. However, now thermophilic temperature systems are also available to take care of this.
No power requirement unlike aerobic composting, where sieving and turning of waste pile for supply of oxygen is necessary	Unsuitable for wastes containing less organic matter
Enclosed system enables all the gas produced to be collected for use.	Requires waste segregation for improving digestion efficiency.
Controls Green House Gases emissions.	
Free from bad odour, rodent and fly menace, visible pollution and social resistance.	
Modular construction of plant and closed treatment needs less land area.	
Net positive environmental gains.	
Can be done at small scale.	
Landfill gas recovery	
Least cost option.	Greatly polluted surface run-off during rainfall
The gas produced can be utilized for power generation or as domestic fuel for direct thermal application.	Soil/groundwater aquifers may get contaminated by polluted leachate in the absence of proper leachate treatment system.
Highly skilled personnel not necessary.	Inefficient gas recovery process yielding 30–40% of the total gas generation.
Natural resources are returned to the soil and recycled.	Balance gas escapes to the atmosphere (significant source of two major green house gases, carbon dioxide and methane)
Can convert low lying marshy land to useful areas.	Large land area requirement
	Significant transportation costs to far away landfill sites may upset viability.
	Cost of pre-treatment to upgrade the gas to pipeline quality and leachate treatment may be significant.
	Spontaneous ignition/explosions due to possible build up of methane concentrations in atmosphere.
Incineration	
Most suitable for high calorific value waste, pathological wastes, etc.	Least suitable for aqueous/high moisture content/low calorific value and chlorinated waste.
Units with continuous feed and high through-put can be set up.	Excessive moisture and inert content affects net energy recovery; auxiliaryfuel support may be required to sustain combustion.
Thermal energy recovery for direct heating or power generation.	Concern for toxic metals that may concentrate in ash, emission of particulates, SO*x*, NO*x*, chlorinated compounds, ranging from HCl to dioxins
Relatively noiseless and odourless.	
Low land area requirement.	
Can be located within city limits, reducing the cost of waste transportation.	High capital and operation and maintenance costs.
	Skilled personnel required for O&M.
Hygienic.	Overall efficiency low for small power stations.
Pyrolysis/gasification	
Production of fuel gas/oil, which can be used for a variety of applications.	Net energy recovery may suffer in case of wastes with excessive moisture.
Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense.	High viscosity of pyrolysis oil may be problematic for its transportation and burning.

proportion of paper, plastics and other combustibles. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions. It also makes the waste rather unsuitable furthermore. Chemical conversion (incineration, pyrolysis/gasification) for energy recovery as heat must first be supplied to remove moisture. For determination of the energy recovery potential and the suitability of waste treatment via biochemical or thermo-chemical conversion technologies the important chemical parameters to be considered includes volatile solids, fixed carbon content, inerts, calorific value (CV), C/N ratio (carbon/nitrogen ratio), and toxicity. Usually 100 tons of raw MSW with 50–60% organic matter can generate about 1–1.5 MW power, depending upon the waste characteristics. The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes is given in Table 10 and advantages and disadvantages of various technological options for energy recovery given in Table 11.

7. Conclusions

The various technologies for recovering useful energy from MSW already exists and are being extensively used in different

countries for their benefits. Hence, an attempt is made in this review article, to study and discussed advantages and disadvantages of the various technological options available for energy recovery/generation from municipal solid wastes in Indian context. It has also been reported that the integrated waste management systems coupled with reduction in waste load and energy potential necessary for the success of sustainable development. This paper shows that a waste-to-energy facility is not only possible but necessary in order to meet the demands of a growing city, improve environmental conditions, and be an example for cities in India as well as in other developing countries.

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